Do Coronal Holes Affect Chromospheric Oscillations?

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Abstract

Several recent investigations have shown that the plasma topography and chromospheric oscillations interact readily. Regions where the ratio of plasma and magnetic pressures are of order unity and the partitioning of the plasma's magnetic topology into open and closed regions have been demonstrated to be important in understanding the observations. To address the latter, using a new TRACE UV continua sequence, we study the properties of chromospheric oscillations in a place where open and closed magnetic topologies can be readily observed in the same field of view; an (equatorial) coronal hole.

Question

We ask the following:

At the formation levels of the TRACE UV continua (in the upper photosphere or low chromosphere) can we see that the topographic structure of the coronal hole influences the passage of chromospheric oscillations and can the influence be measured ?

As a result of our study we show that there is a significant contrast in the signal phase-difference and travel-time between the portions of the TRACE field-of-view that are inside and outside of the coronal hole. For example, the derived travel-time of oscillations between the UV continua (in the frequency range of running sound waves; 6-8 mHz) inside the coronal hole is approximately 8 seconds while that outside is of the order of 4 seconds.

This result poses some interesting questions about the coronal hole, it's magnetic topology and significant changes in the plasma's thermodynamic stratification inside compared to that outside.

TRACE INO Program Overview

The chromosphere is an important component in the flow of energy from the Sun's core to the Earth. Recent research has once again raised questions about the role of atmospheric oscillations in supplying the mechanical energy required to heat and maintain the structure of the ambient chromosphere. The key to understanding these oscillations is knowledge of their interplay with the magnetically threaded medium in which they travel. To this end, we discuss the mapping of the chromospheric plasma topography through the analysis of simultaneous SOHO and TRACE time-series observations. The combination of Fourier and Wavelet based analysis techniques applied allows us to construct a picture of the chromospheric plasma and its interaction with the wave modes present. This approach will form an observational test-bed for future observatories, theories and advanced simulations of mode-conversion, dissipation and wave heating in the chromosphere.

Oscillations Vs. Topography

McIntosh et al. (2001) proposed that observational signature of the propagation of magneto-atmospheric waves would be significantly altered by variations of the atmosphere's magnetic topology through:

- **Variations in the region where the plasma-β is of order unity.**
- **Partitioning of the atmosphere into open and closed field structures on a range of scales.**

Recent theoretical studies [Cally 2001] and investigations using advanced multi-dimensional MHD models [Rosenthal et al. 2001 ; Bogdan et al. 2004] have demonstrated these effects and considerably advanced their discussion.

These simulations and observational investigations of MA wave behavior are running hand-in-hand.

[McIntosh et al., 2001, ApJL, **548**, 237]
[Cally 2001, ApJ, 548, 473]
[Rosenthal et al. 2002, ApJ, **564**, 508]
[Bogdan et al. 2004, **599**, 629]

Phase-Difference Analysis

Phase-difference between two bandpasses D_1, D_2 ⇒ Wave Properties!!

(at frequencies above the acoustic cut-off frequency)

$$\Delta\phi_{21} = k_z.\Delta z_{21} \sim (\omega/c_s).\ \Delta z_{21}$$

FFT : $D_\nu(x,y,t) \to F_\nu(x,y,\nu)$

Signal Cross-Power, $CP_{21}(x,y,\nu)$

$$CP_{21} = |\langle F_1.F_2^*\rangle| / \langle |F_1.F_2^*| \rangle$$

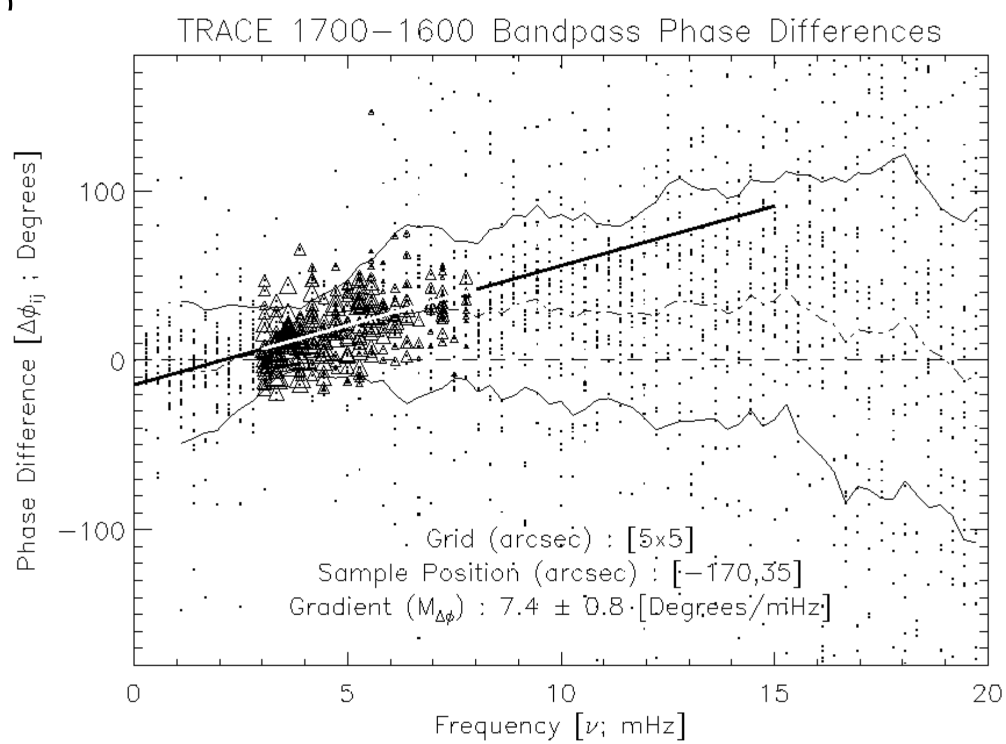
Phase-Difference, $\Delta\phi_{21}(x,y,\nu)$

$$\Delta\phi_{21} = \mathrm{Arg}\{CP_{21}\}$$

Quantify phase-difference behavior spatially

⇒ phase-difference gradient $M_{\Delta\phi}(x,y)$.

$$M_{\Delta\phi 21} = d(\Delta\phi)/d\nu \sim \Delta z_{21}.\ V_{phase}$$



5x5 TRACE pixel Δφ versus ν scatter & $M_{\Delta\phi}$

[McIntosh, Fleck & Judge 2003, A&A, **405**, 769]

Travel-Time Analysis

- Try to resolve $M_{\square\square}$ ambiguity
- Easier to understand.

Two oscillations, one slightly out of phase

f_1= A exp(i□t)

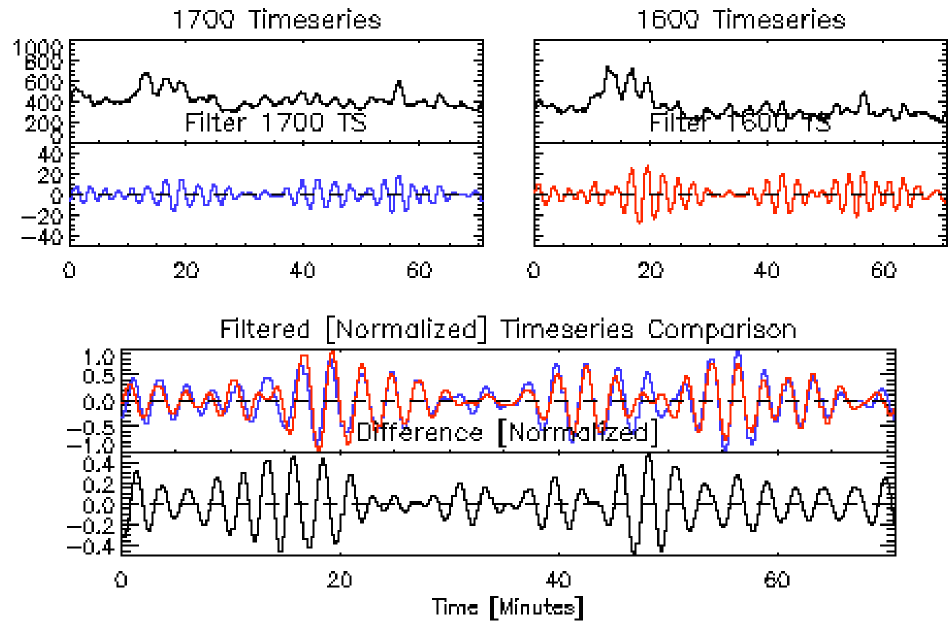
f_2= B exp(i□t + □□)

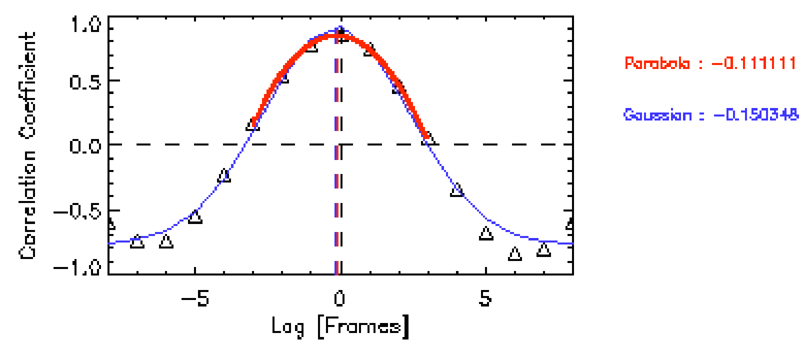
□□ equivalent to travel-time, □t

□ **□t$_{21}$ = □□$_{21}$/□ = □(□□$_{21}$)/2□**

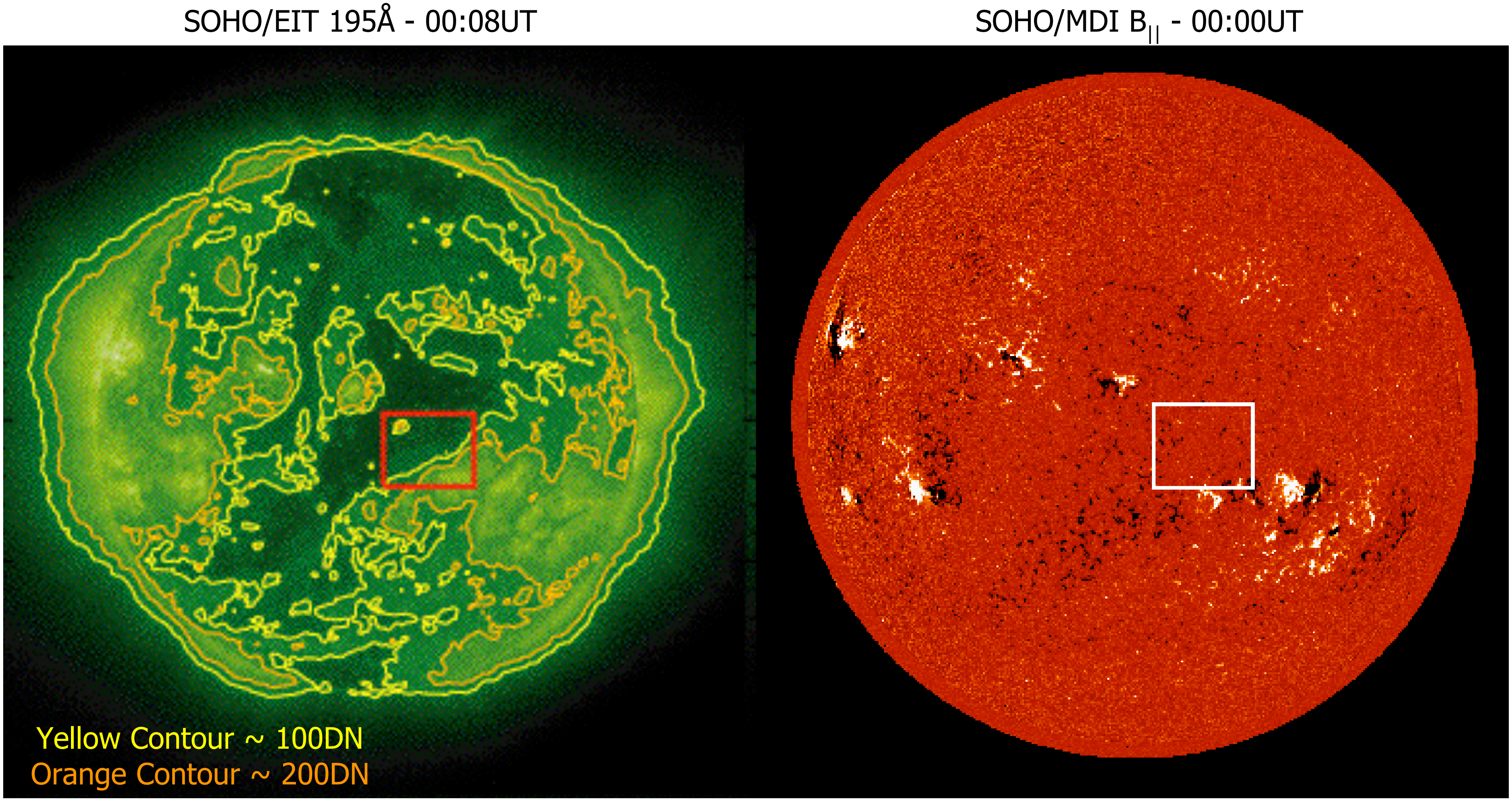
□ Travel-Time (TT) maps

- Choose frequency, □
- Gaussian filter timeseries, G(□,□□)
- Cross-Correlate (CC) filtered timeseries
- Fit CC function to obtain sub-exposure □t
- □t equivalent to "lag-time".
- Yields mean travel-time over timeseries.



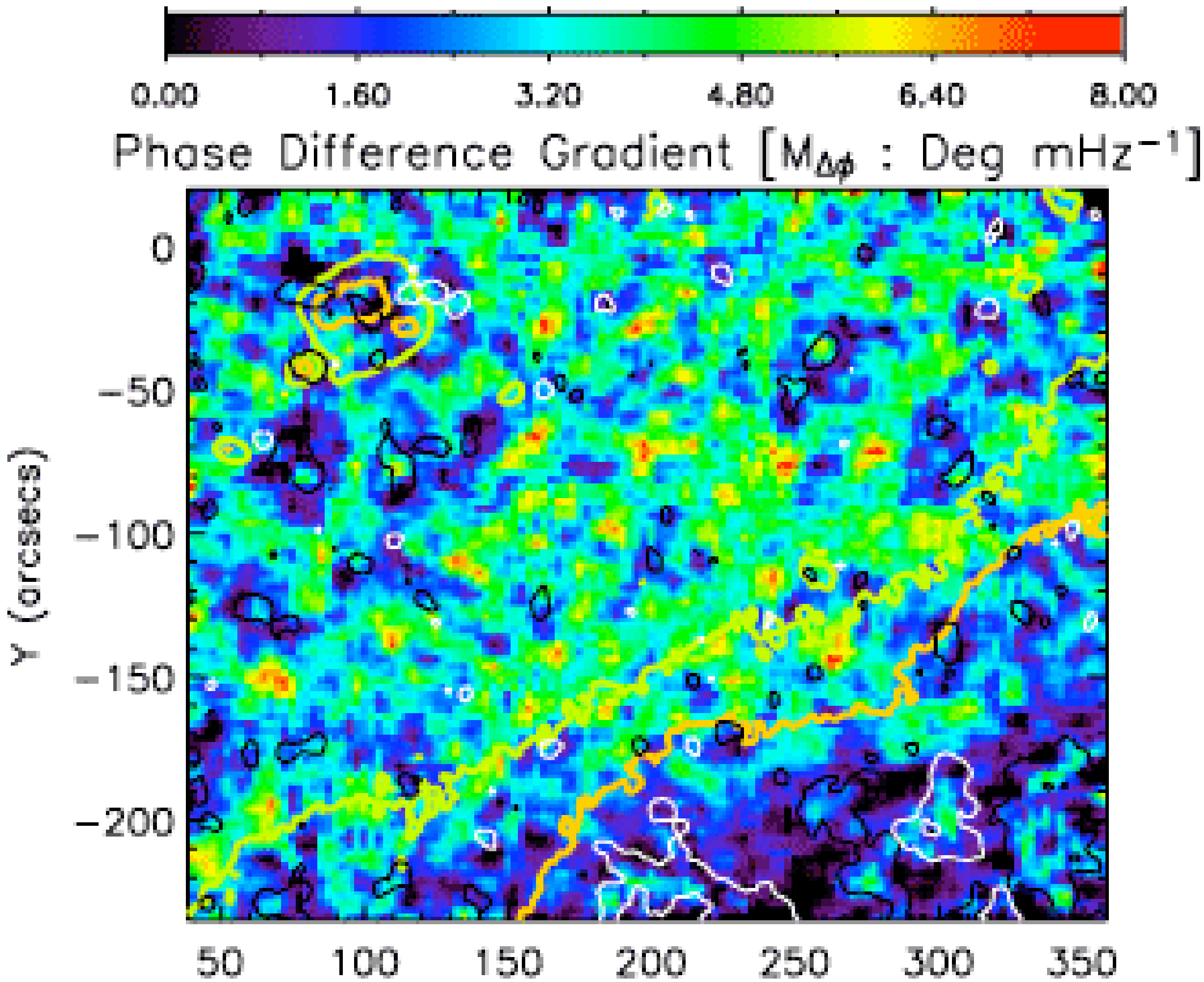


July 14 2003



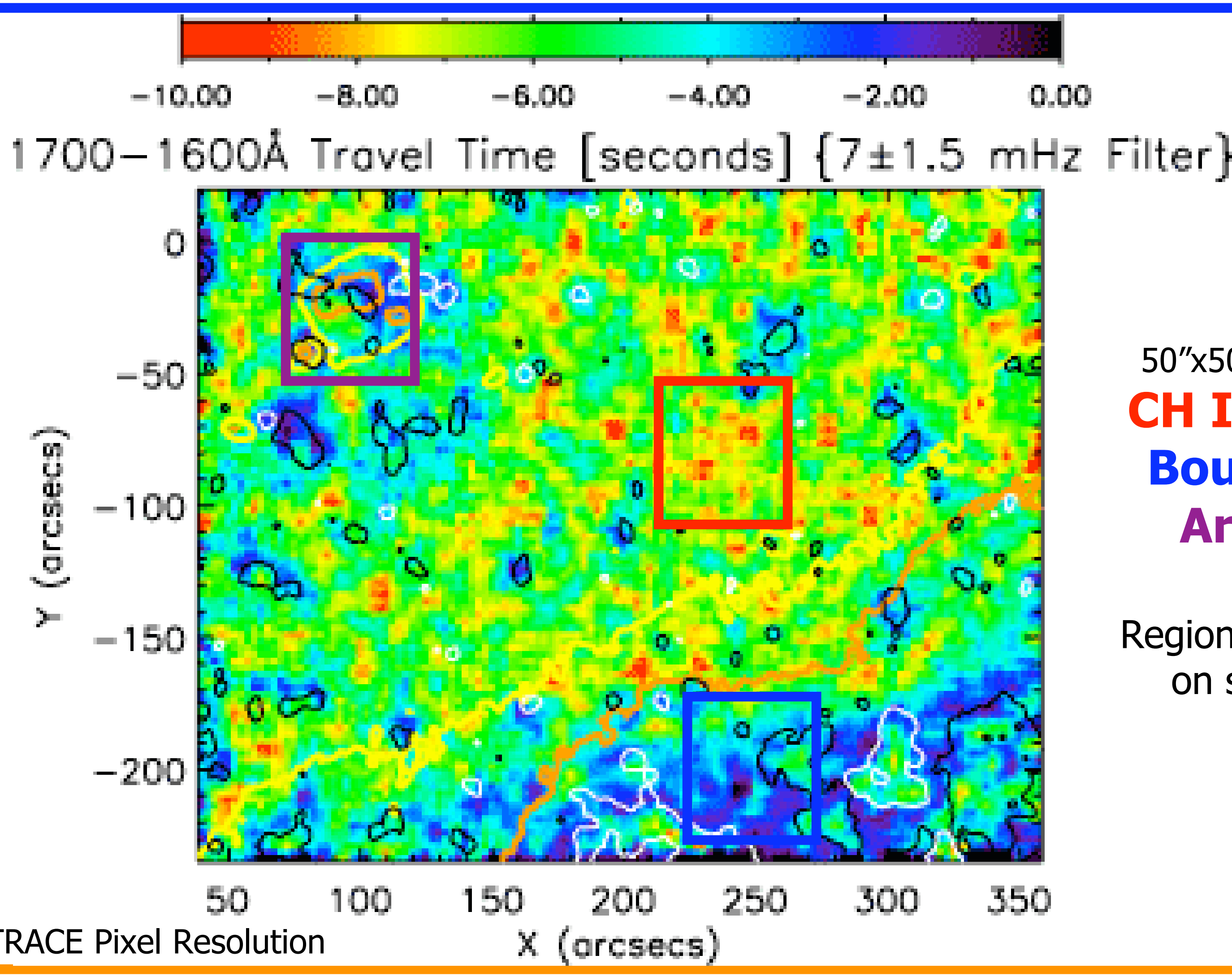
[From McIntosh, Fleck & Tarbell 2004, Submitted ApJL]

Phase Difference ($M_{\Delta\phi}$) Map



5x5 TRACE Pixel Resolution

Travel-Time (TT) Map

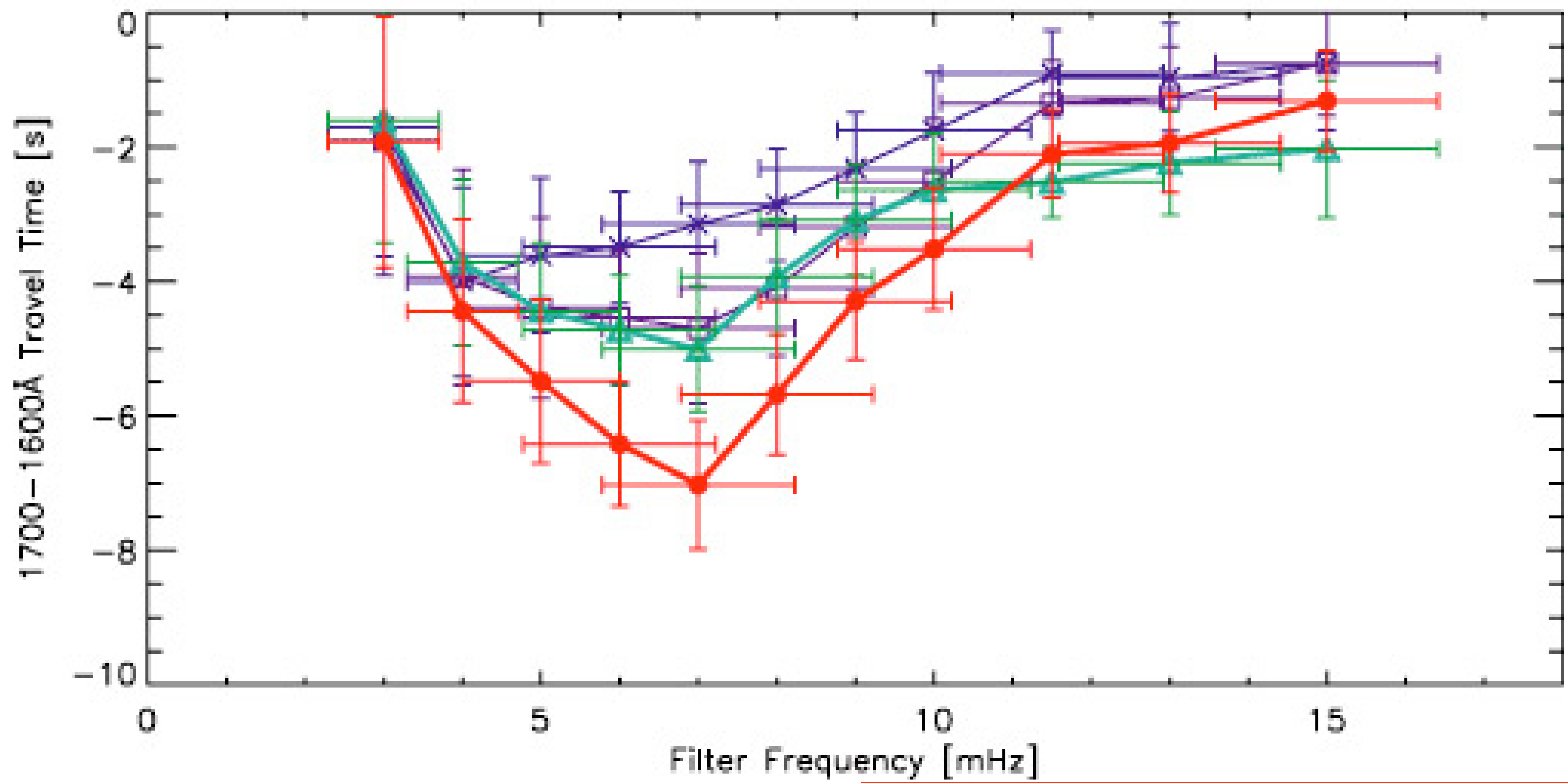


5x5 TRACE Pixel Resolution

50”x50” Regions
CH Interior
Boundary
Arcade

Regions sampled on slide 11

Travel-Time Vs. Freq



- Blue curve shows suppression
- Purple - Green curves match
- Red - Green curve departure

Compare Red & Green Curves
□z - □z ≈ 30km
□ **HUGE** change in structure

Comparison of Features

• Large contrast in M$_{□□}$ & TT.

• Both differ from QS values (see Appendix 1).

• Region at bottom right topologically different from rest of region.

□ **Complex magnetic topology?**

• Difference @7mHz in □z - □z **~30km**

□ **Change in stratification?**

So, does the structure of the coronal hole affect the chromospheric oscillations?

Discussion Points

Unfortunately $M_{\square\square}$ and TT are not unique diagnostics, but assuming a frequency filter of 7mHz we can look at the path traveled by sound waves near the temperature minimum. We see,

- In the CH interior the stratification of the atmosphere is different from both its boundary region **and** from (very) quiet Sun regions.
- The difference is a significant fraction of a scale-height (100km) at the base of the chromosphere.
- The difference is exaggerated further at the poles (see Appendix 4).

It is fair to say that the chromospheric oscillations are affected by the topography of the CH structure. But, this poses a very important question……

Why would the largely hydrodynamic (high plasma-$\square$) CH interior plasma at the base of the chromosphere care about the fact that the magnetic field is open to the interplanetary medium and stratify itself so?

[From McIntosh, Fleck & Tarbell 2004, Submitted ApJL]

Further/Ongoing Work

• Incorporate temporal intermittence of oscillations into analysis. Will allow the analysis of travel-time (phase-differences) for individual "packets" of chromospheric oscillations. (cf. McIntosh & Smillie 2004, ApJ, April 1, 2004).

• Investigate the topographic structure at the base of the chromosphere and it's relevance to solar wind models.

• Correlate observed INO CH structures (see appendices) and their connection to *in situ* measurements of solar wind parameters.

Acknowledgements

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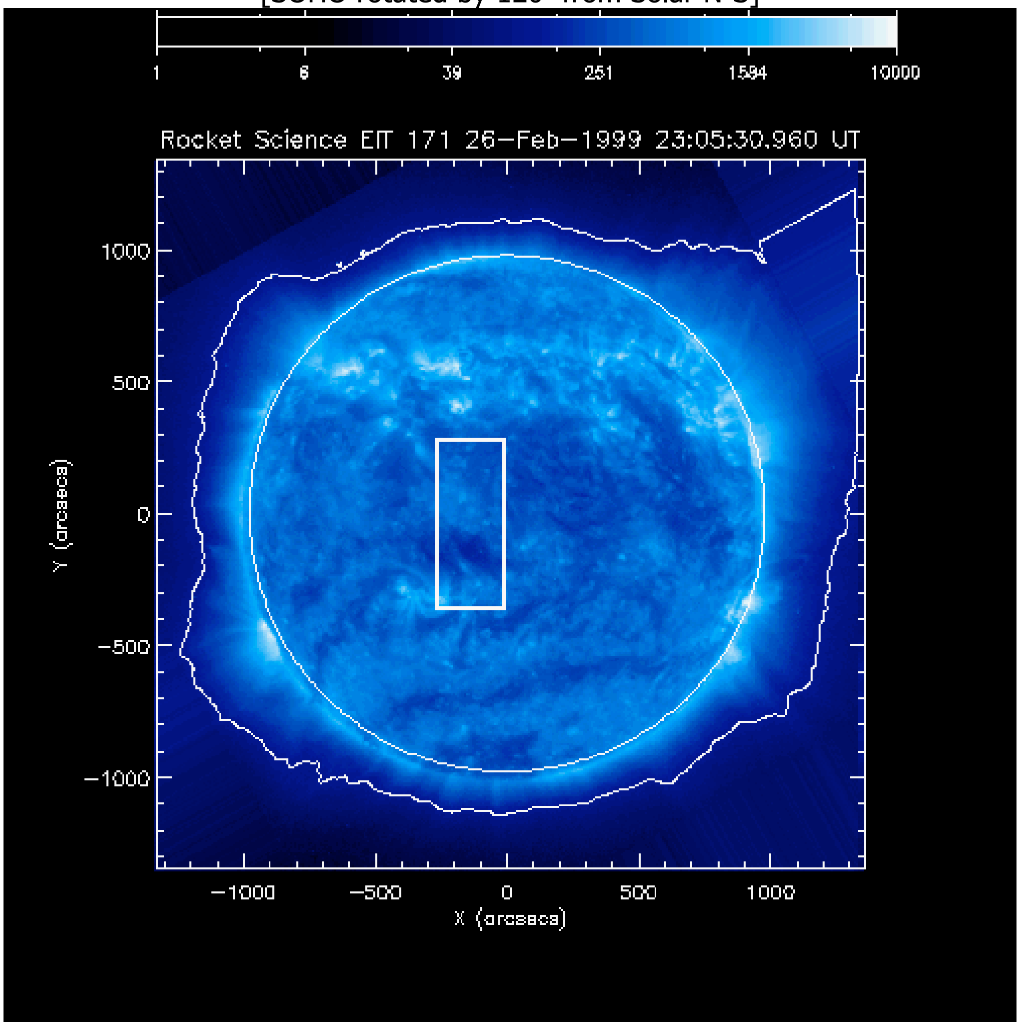
Appendix 1

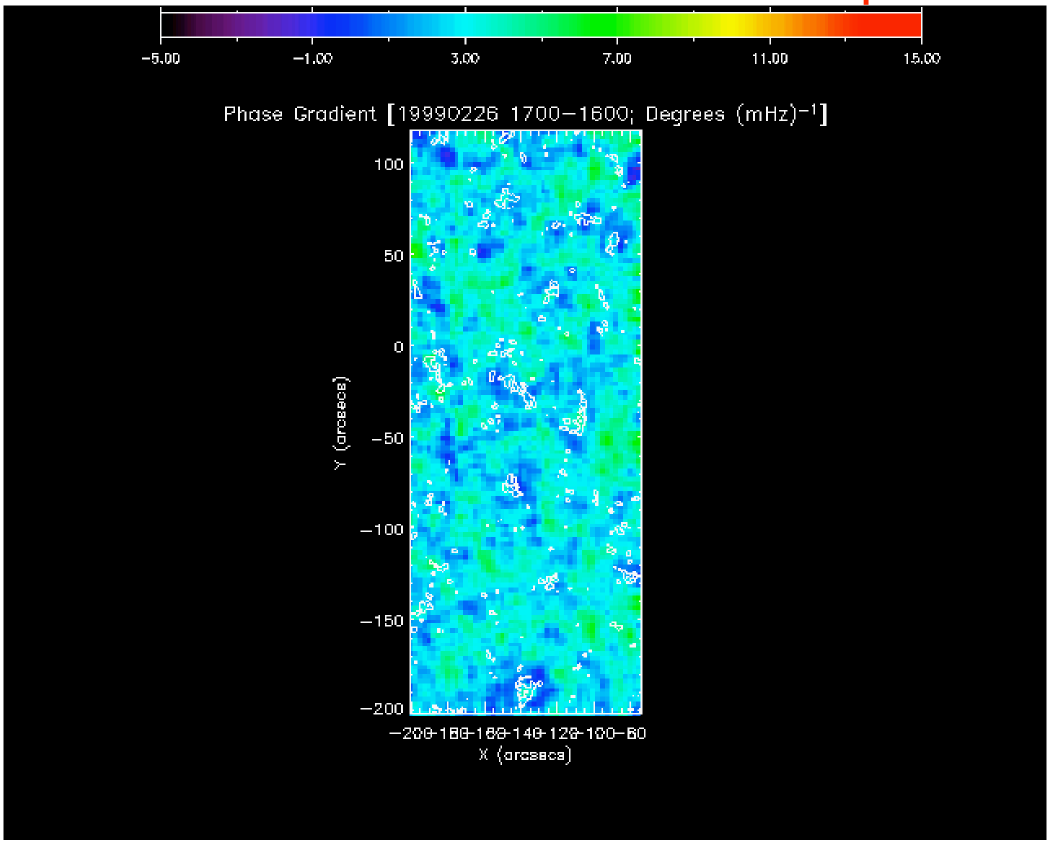
1999, February 26

SOHO/EIT 171Å Context Image

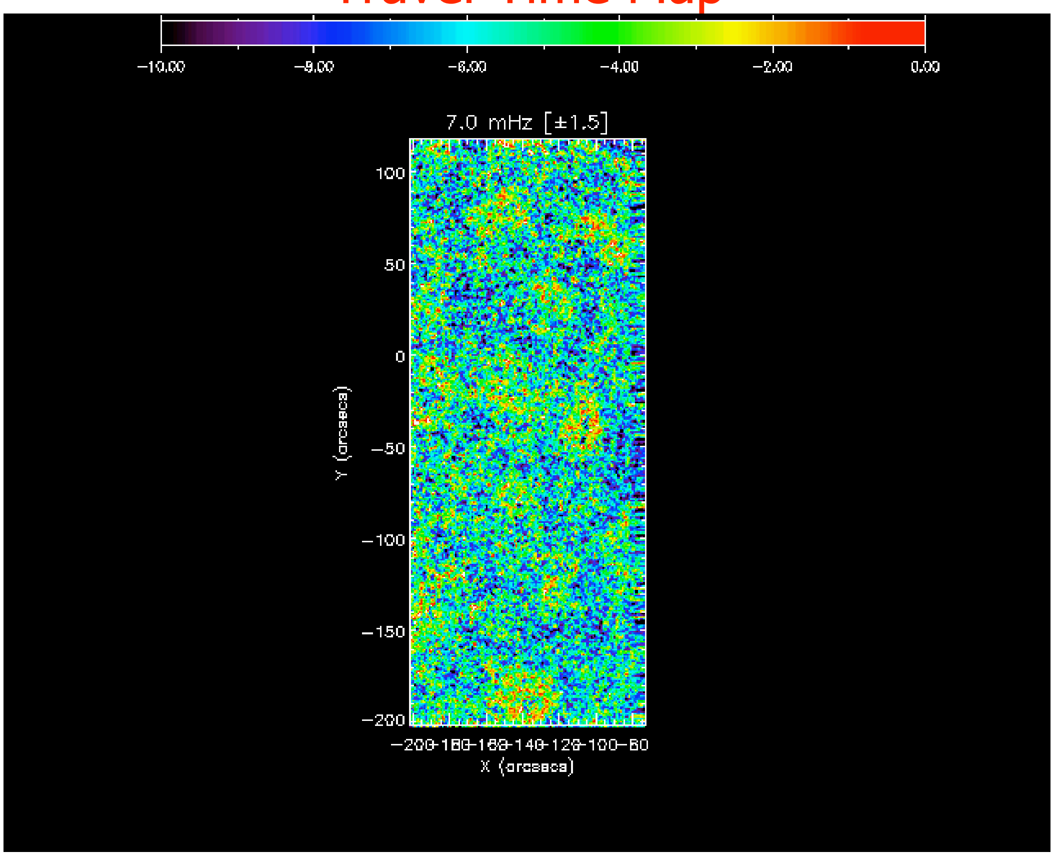
[SOHO rotated by 120° from Solar N-S]



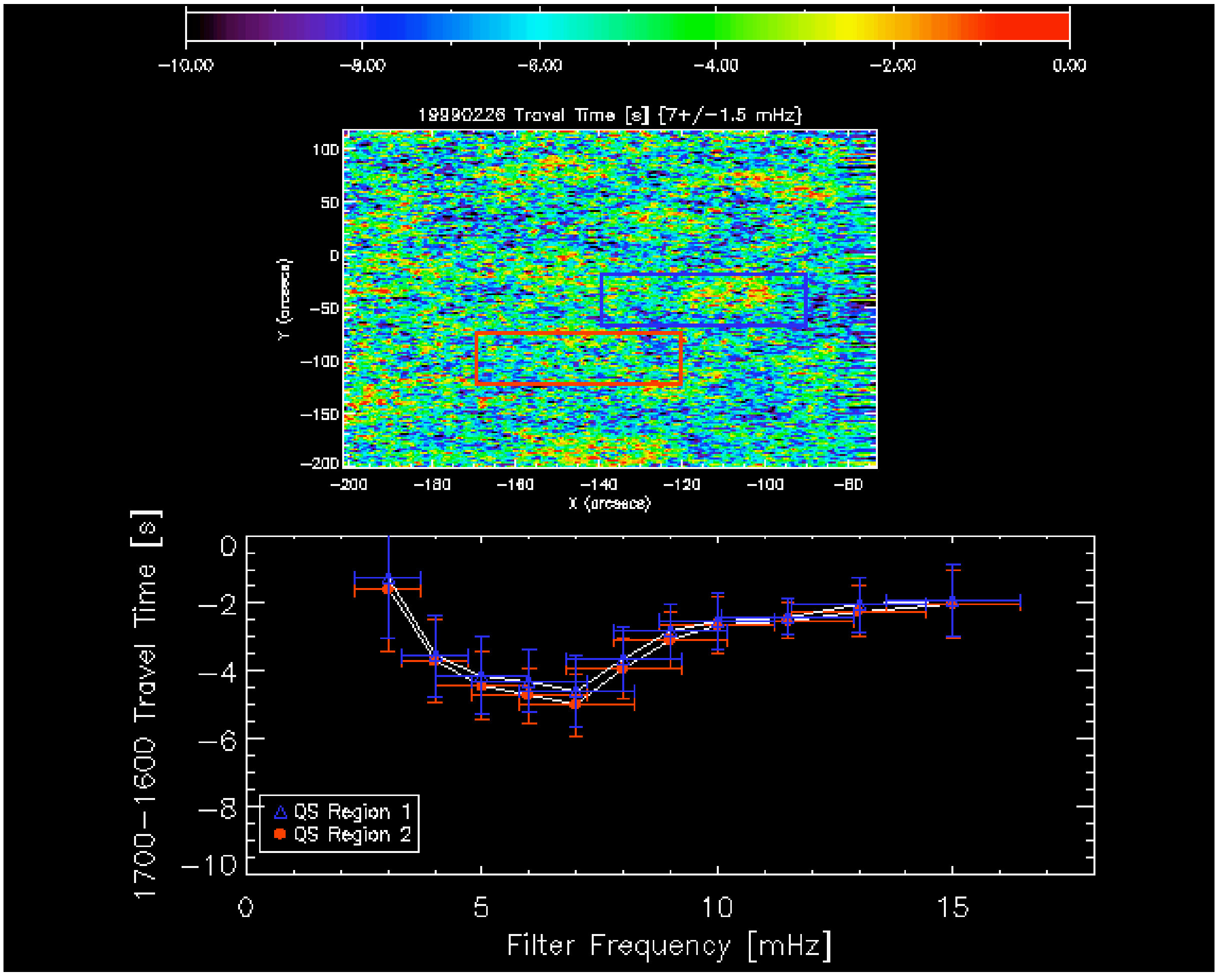
Phase-Difference Gradient Map



Travel-Time Map

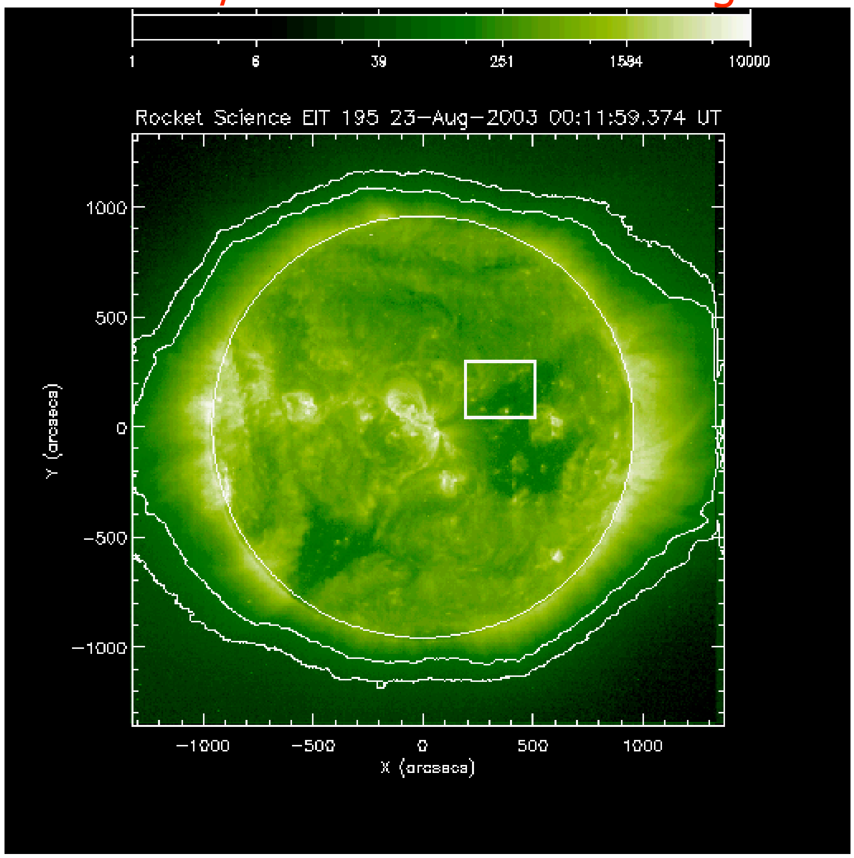


Travel-Time Filter Span

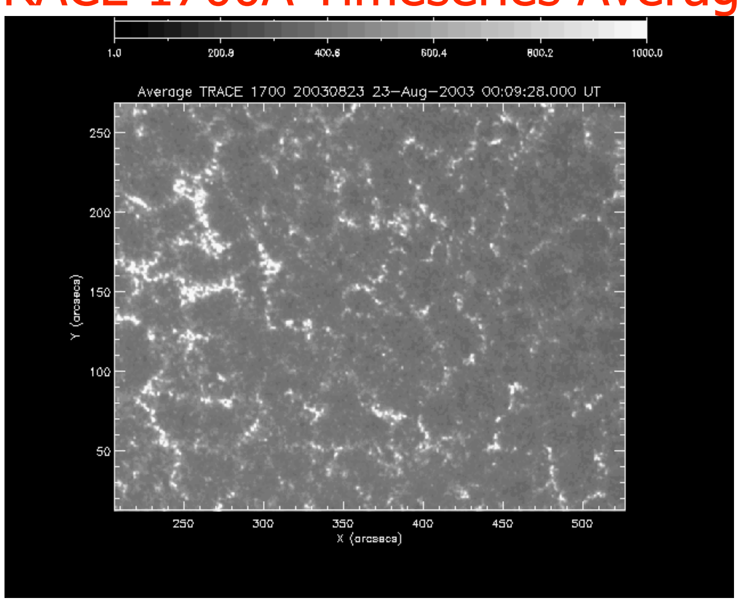


Appendix 2
2003, August 23

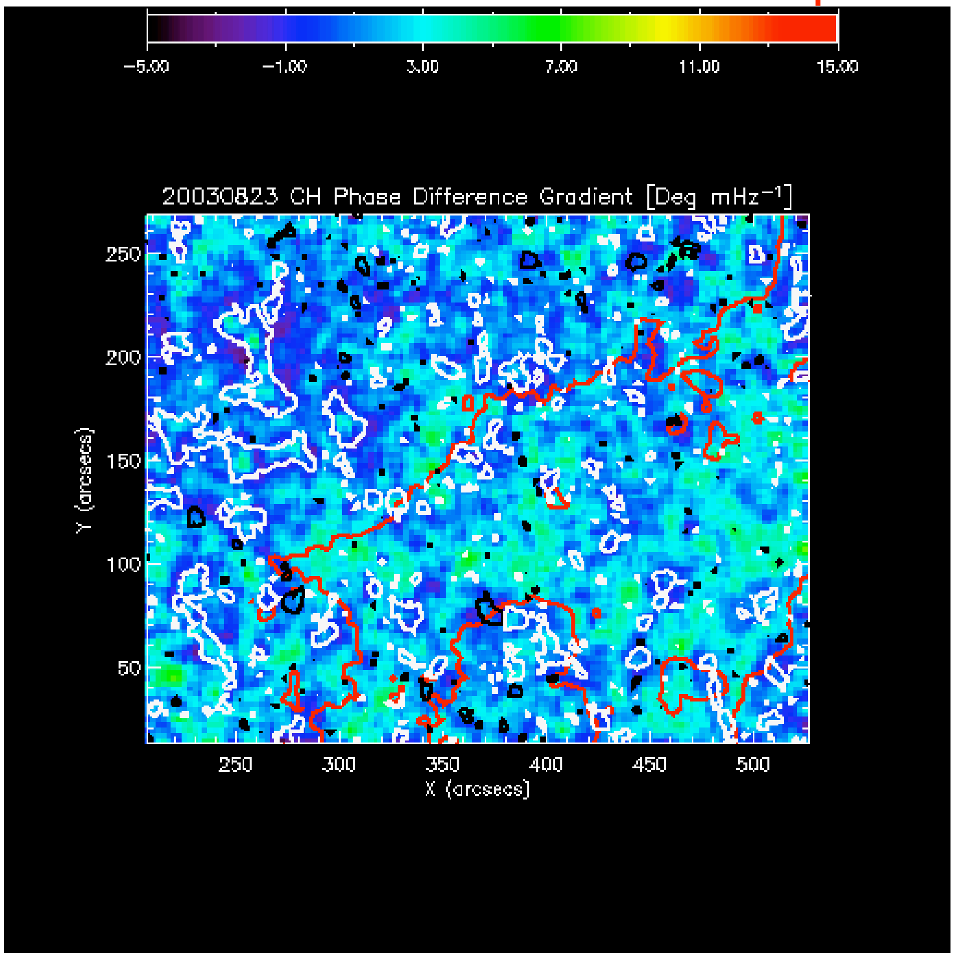
SOHO/EIT 195Å Context Image



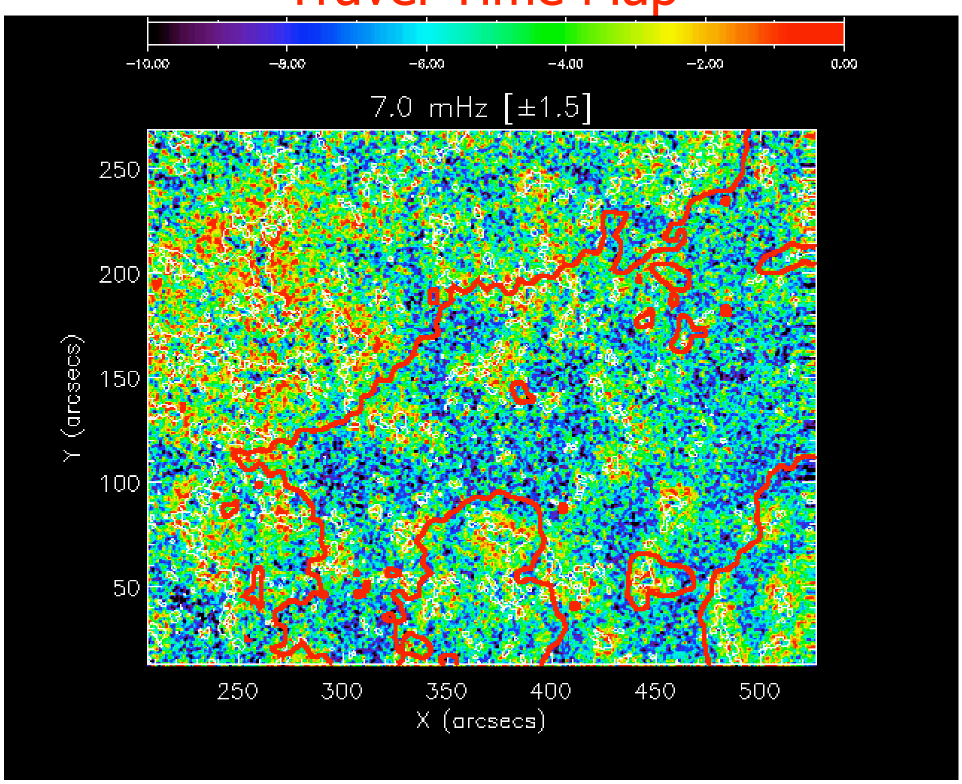
TRACE 1700Å Timeseries Average



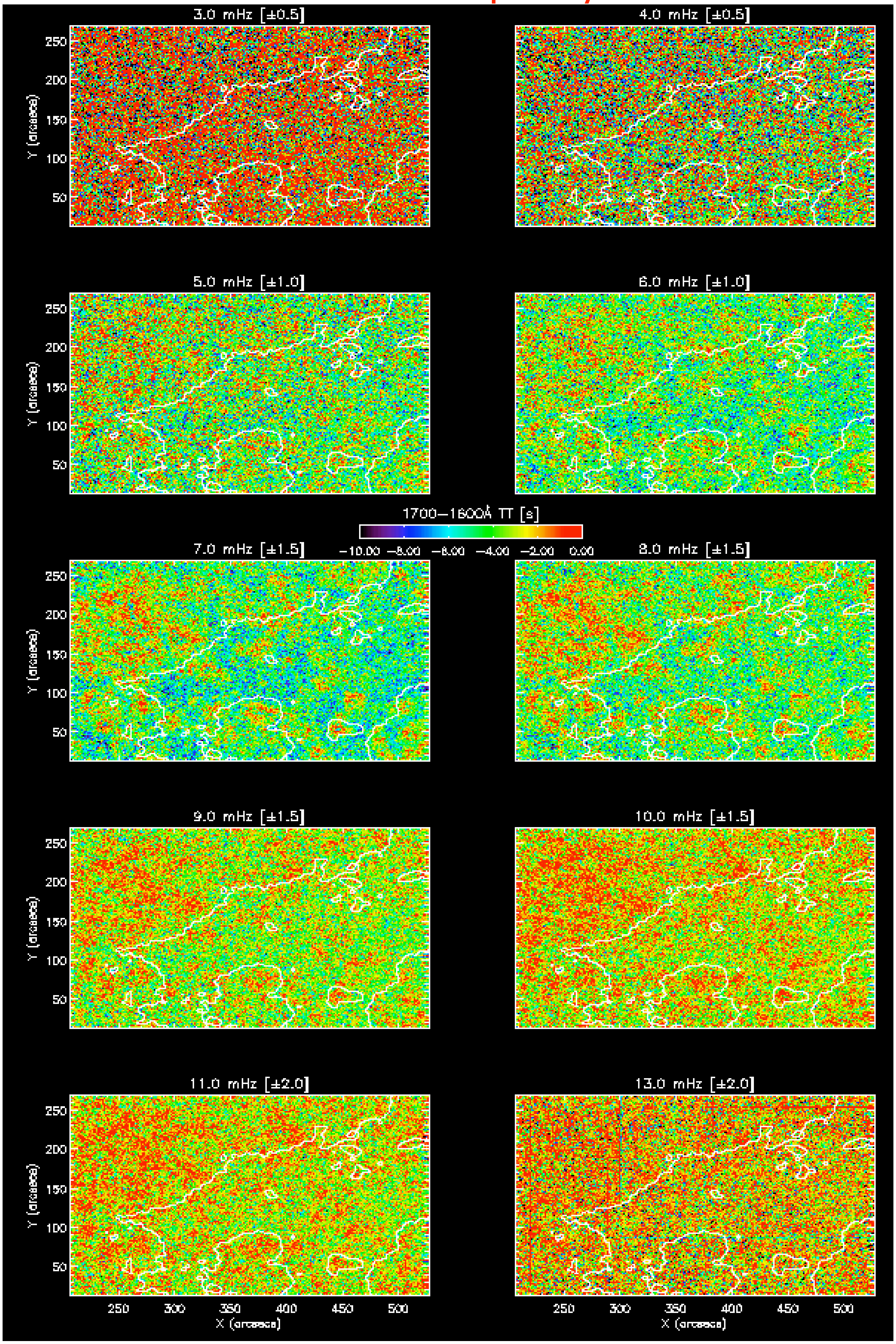
Phase-Difference Gradient Map



Travel-Time Map

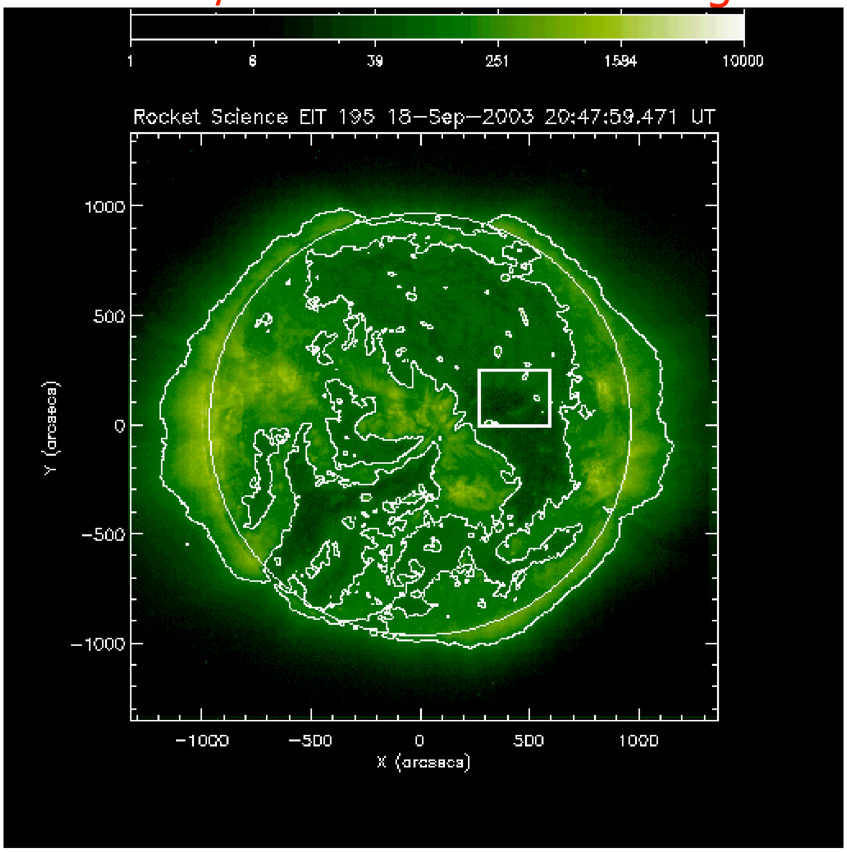


Travel-Time Frequency Scan

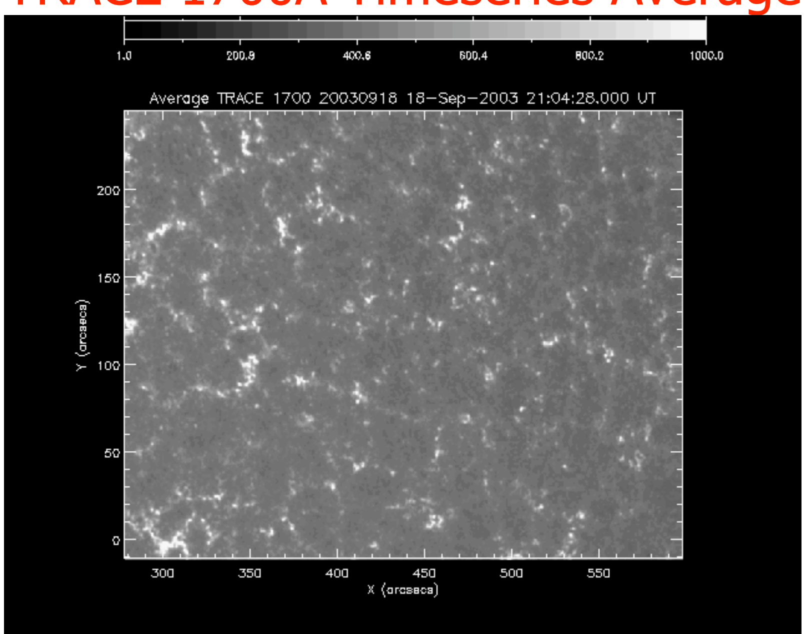


Appendix 3
2003, September 18

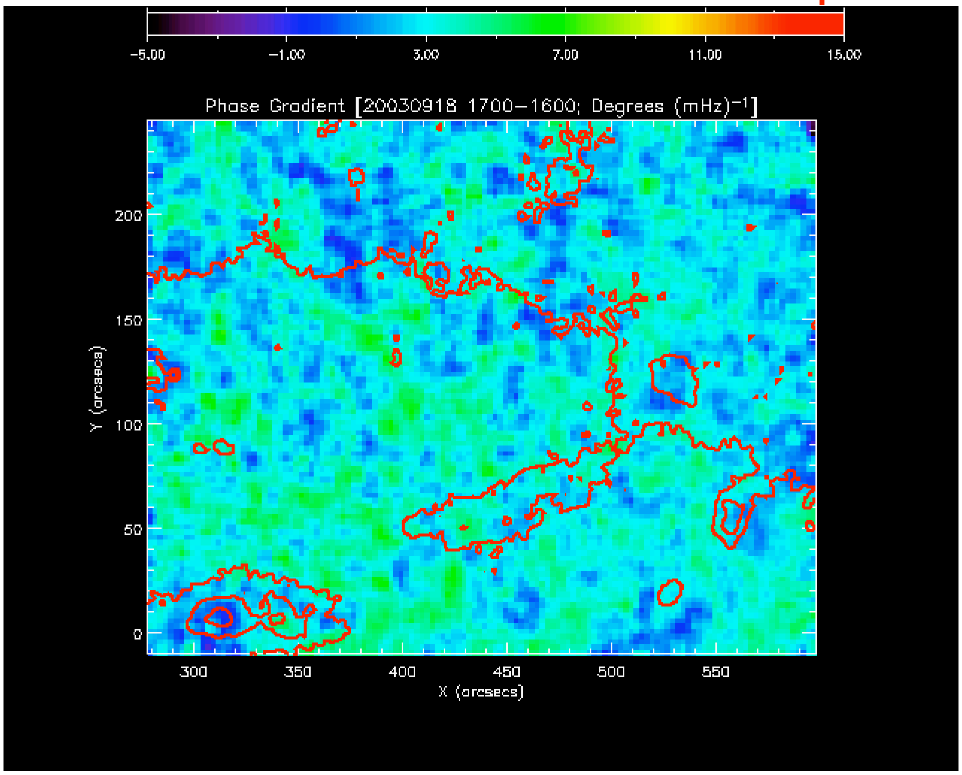
SOHO/EIT 195Å Context Image



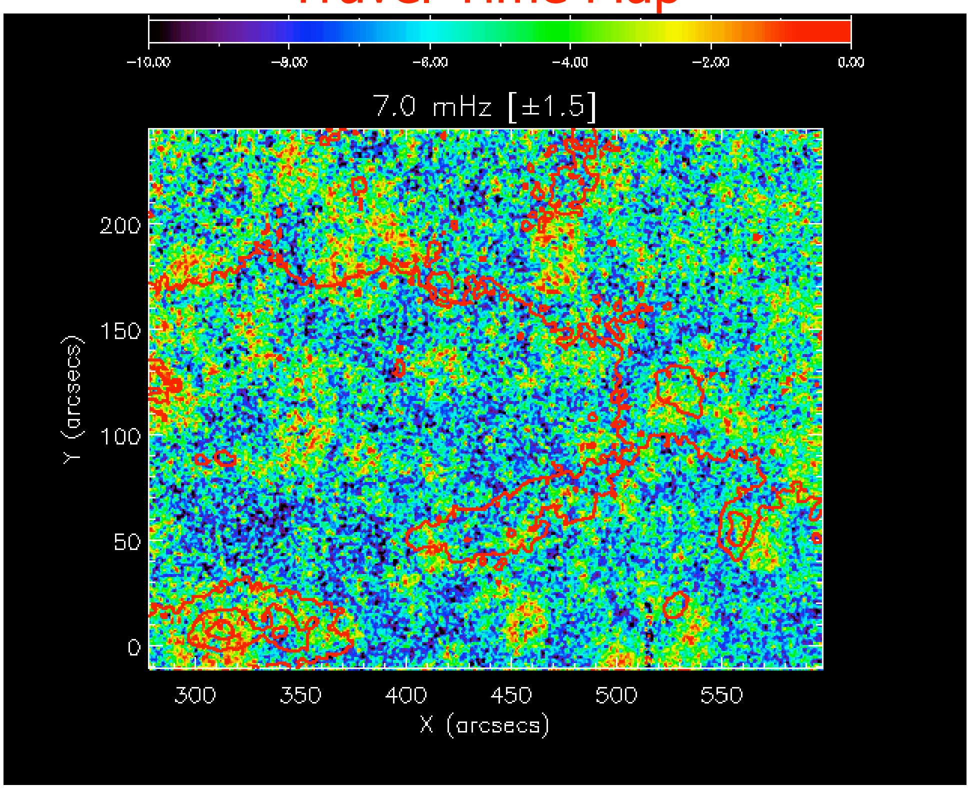
TRACE 1700Å Timeseries Average



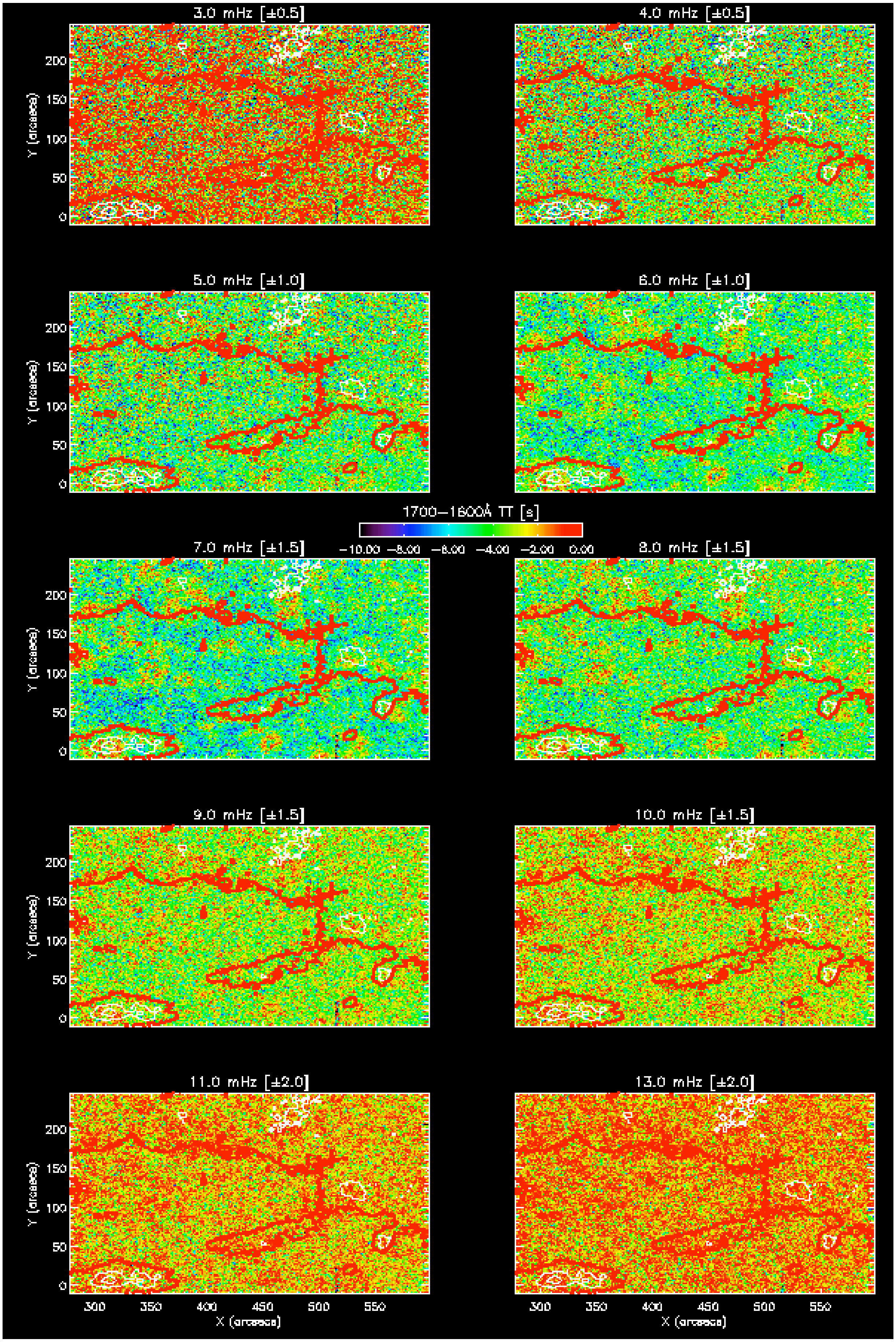
Phase-Difference Gradient Map



Travel-Time Map



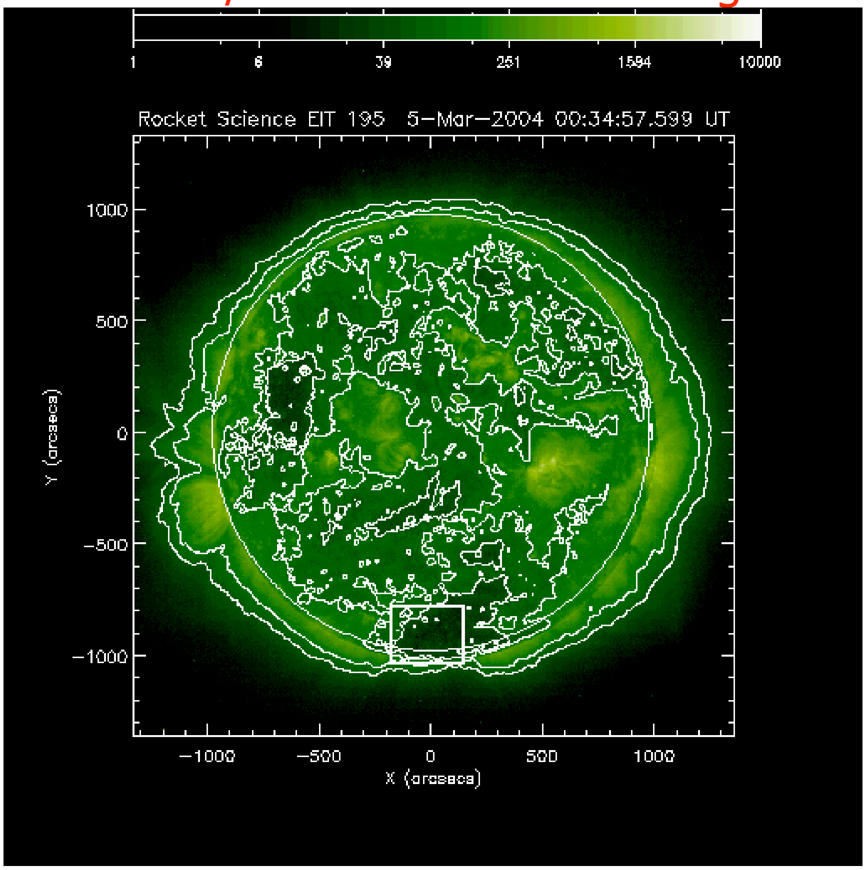
Travel-Time Filter Scan



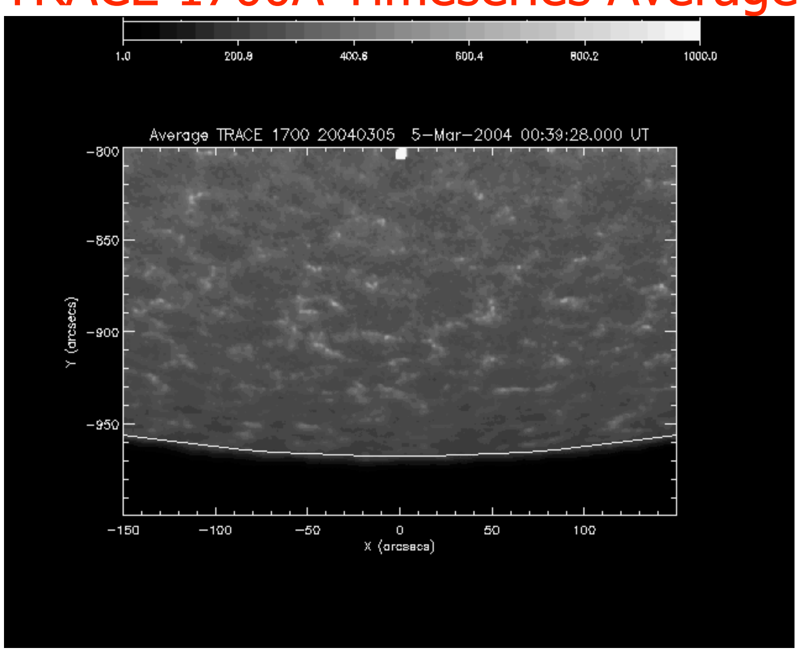
Appendix 4

2004, March 5

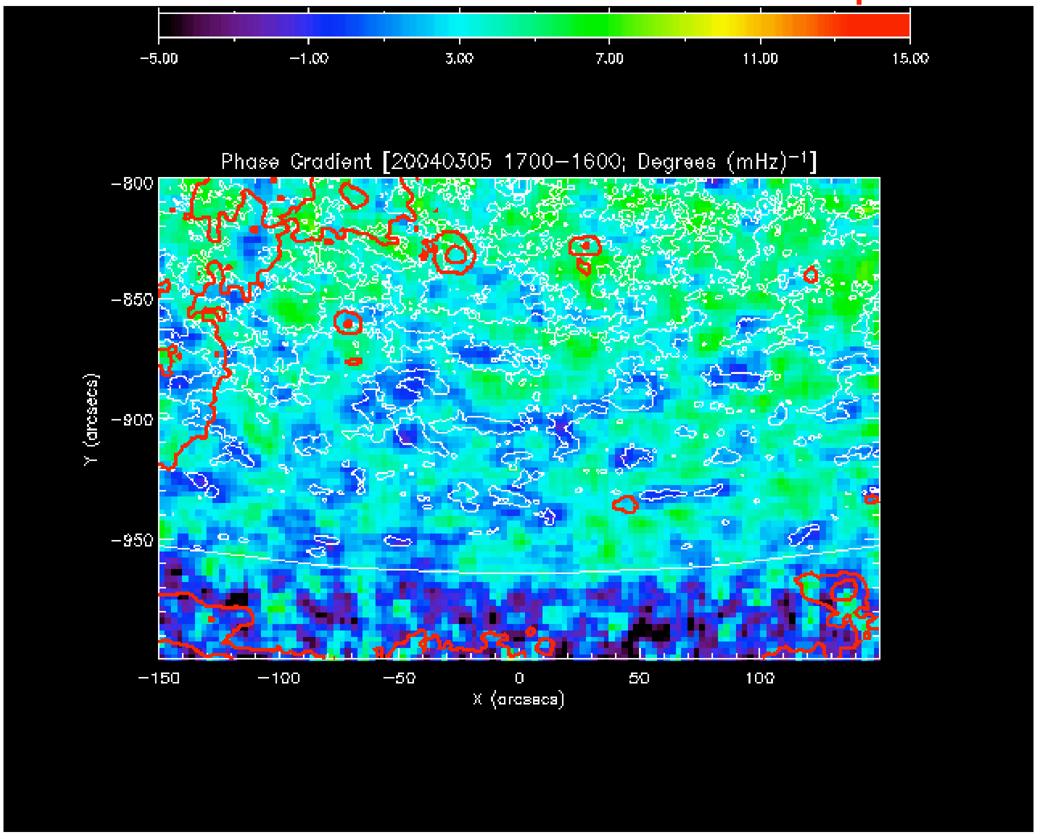
SOHO/EIT 195Å Context Image



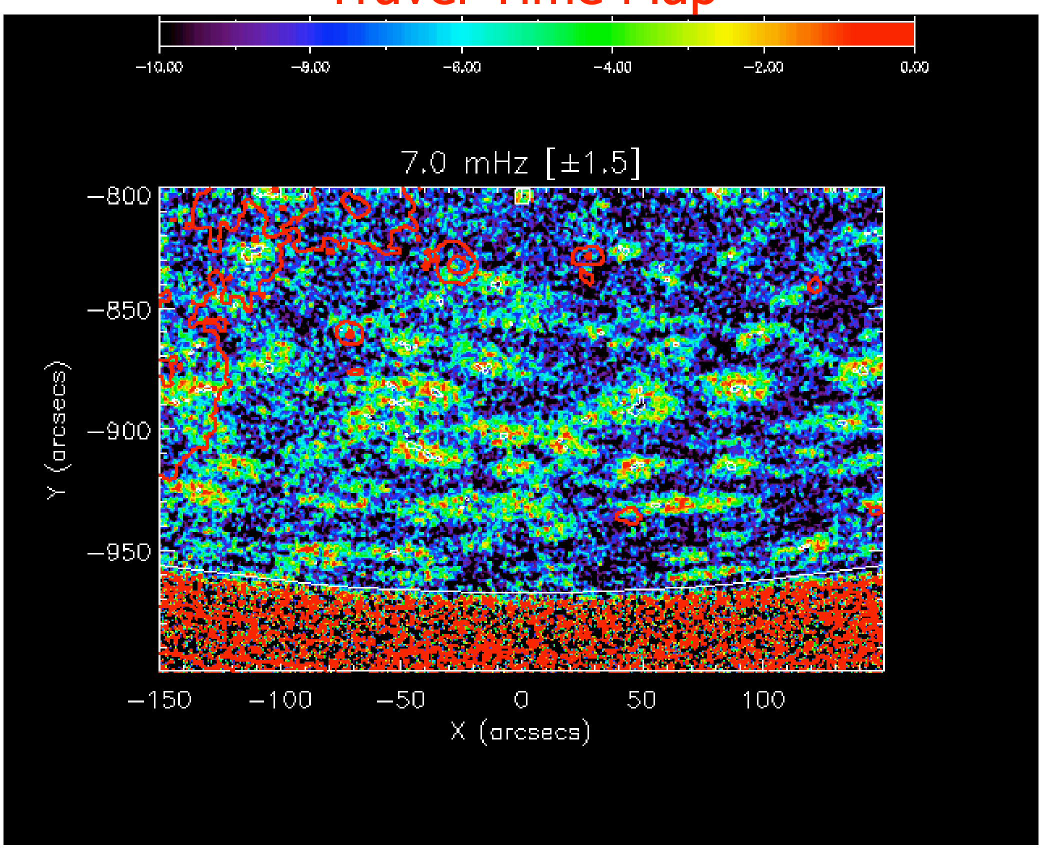
TRACE 1700Å Timeseries Average



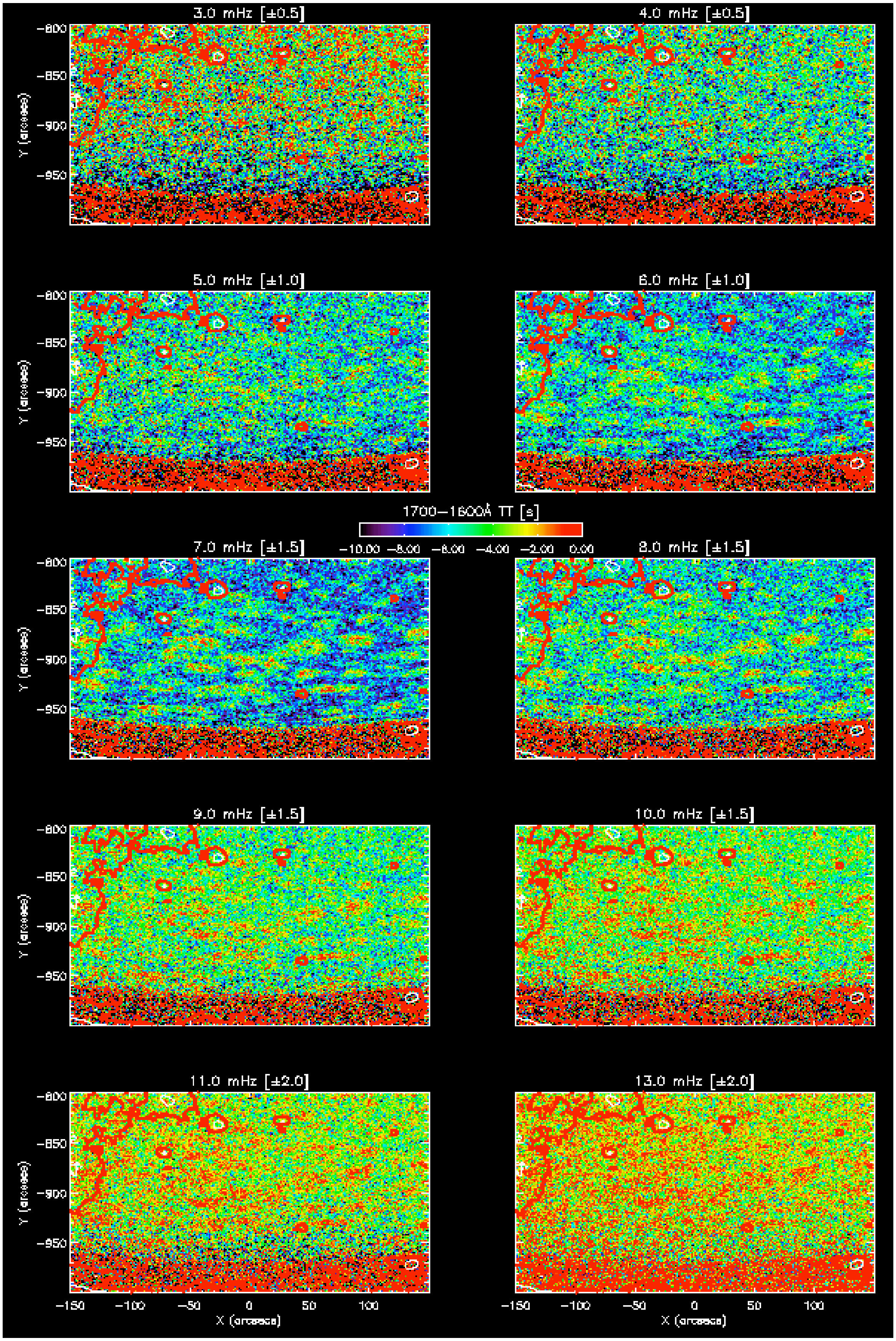
Phase-Difference Gradient Map



Travel-Time Map



Travel-Time Filter Scan



Travel-Time Filter Span